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Such questions as why and how operations research, (OR), and systems analysis originated, what they are, and what contributions they might make to instructional media programs are answered.

OR originated at the outbreak of World War II when military organizations, which had been developing their technology faster than it could be absorbed into tactics and strategy, began applying science to executive-type problems. The potentialities of computers as a new management tool were realized. There are about 10,000 OR workers in the world.

OR is research on problems dealing with the control of organized (man-machine) systems to produce answers that best serve the objectives of the organization as a whole. The research is performed by interdisciplinary teams using scientific methods. Because the OR worker can observe but not manipulate the system he studies, he constructs models on which to conduct his research. The stages of an OR project consist of formulating the problem; constructing the model; discovering a solution; testing the model; and evaluating, controlling, and implementing the solution.

OR can advance educational-media research by developing measures of the effectiveness of education to facilitate curriculum evaluation and modification. The objectives of educational efforts should be defined in a meaningful and measurable way so that tests can be developed. A study is cited in which means were developed to measure the amounts of information, instruction, and motivation communicated by a given message and to measure their value to the sender and receiver. Similar measures should be developed by educators and operations researchers working together to gauge the effectiveness of particular teaching methods and media.

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THE DEVELOPMENT AND NATURE OF OPERATIONS RESEARCH AND ITS RELEVANCE TO EDUCATIONAL - MEDIA RESEARCH

Russell L. Ackoff
Professor of Operations Research
Case Institute of Technology
Cleveland 6, Ohio

U. S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
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INTRODUCTION

This paper tries to answer three questions which were addressed to me by the program committee of this conference:

1. Why and how did operations research (OR) and systems analysis originate and what have they accomplished?

2. What are operations research and systems analysis?

3. What contributions might they make to instructional media programs?

The terms 'operations research', 'systems analysis', 'systems research', 'management science', and others are usually used interchangeably. To the dedicated and devoted there are subtle differences between these which need not concern us here. I will use the term 'operations research' (OR) to represent the entire complex of multi-disciplinary, systems-oriented research activities because it is under this name that most relevant professional and academic activities have been organized.

THE DEVELOPMENT OF OR

The birth of OR is usually dated back to about 1939, but as with other scientific developments, once it was individuated and named, its roots could be traced back far into the history of science and society. Even the oldest scientific disciplines, the natural sciences, were individuated and named only about a century ago, but once they were, scholars went back through history and identified earlier work with the new names. Newton, for example, was known as a natural philosopher in his own day, not as a physicist.

Although the roots of OR may extend back beyond the first Industrial Revolution, it was certainly in this revolution that the need which OR was to fill began to develop. Until the middle of the last century most industrial enterprises employed only a handful of men. The advent of machine tools, the replacement of man by machines as sources of power and the development of national transportation and communication systems fertilized industry and it began to grow into its present mature form. As companies grew, it became less and less possible for one man to manage them so the boss divided his job into parts which he assigned to others. For example, managers of production, marketing, finance, personnel, and research and development began to appear. With further industrial growth even these functions were subdivided; for example, production was sometimes divided into procurement or purchasing, maintenance, traffic, quality control, production scheduling, and so on. As populations grew and spread, new markets were formed and new sources of raw material were discovered. Consequently, these functions were dispersed geographically. Multiple production facilities and sales offices became commonplace and each required its own management. Thus the functional and geographic segmentation of management as we know it today was a natural consequence of the industrial growth brought about by the first Industrial Revolution.

New types of applied science developed to provide assistance to each new type of management as it appeared. For example, the application of physics and chemistry to problems of production led to mechanical and chemical engineering. Later, with the addition of techniques and substantive knowledge supplied by statistics and psychology, industrial engineering also developed. Market research, industrial (micro) economics and industrial psychology and sociology were other management-oriented, applied-scientific disciplines that appeared. As more specialized forms of management emerged, so did more specialized applications of science; for example, materials-handling engineering, statistical quality control, maintenance and reliability engineering, advertising research and so on.

An important aspect of this development lies in something that did not happen: science was not applied to the emerging executive function. To understand the nature and significance of this fact let us first make clear the distinction between the executive and the management function. Each time a managerial function is broken down into a set of different subfunctions a new task is created, that of integrating the diverse subfunctions to serve efficiently the interests of the whole. The integrating task is the executive function.

It is the executive's responsibility to establish policies and practices that in some sense best serve the interests of the organization as a whole -- not the interests of any one function reporting to him. This integrating task requires taking the whole system into account.

The executive function in industry developed gradually as did the organizations themselves. The executive was not subjected to violent stimuli from new technology as was, for example, the production manager. The executive

grew into his problems and they appeared to require for their solution nothing but good judgment based on relevant past experience. The executive, therefore, felt no need for a more rigorous scientific way of looking at his problems. However, increasingly heavy demands were made on his time and he sought aid from those who had more time for and more experience with the problem at hand than he had. It was this need that gave rise to management consultants but their activity was not based on the use of science or scientific research.

This lack of development of the application of science to executive-type problems might have continued indefinitely had it not been for what happened within military organizations at the outbreak of World War II. Military organizations had gone through the same type of organizational evolution as had industry, and for the same reasons. The development of new technologies and growth requires increased division and specialization of managerial skills. Four major managerial functions appeared in the military: administration (G 1), intelligence (G 2), operations and training (G 3) and supply and logistics (G 4). Each of these was in turn divided into various types of sciences (e.g. G 4 was divided into ordnance, signal, transportation, engineering, and so on) and these were further subdivided and, as in the industrial case, more and more widely dispersed geographically.

The major difference between the evolutionary development of military executives and of their industrial counterparts was to be found in the twenty-year gap between the close of World War I and the opening of World War II. During this period military technology was being developed more rapidly than it could be absorbed effectively into military tactics and strategy. Little wonder then that British military executives and managers turned to scientists for aid when the German air invasion of Britain began. Specifically, they

sought aid in incorporating the then-new radar into tactics and strategies of air defense. Small teams of scientists, drawn from any disciplines from which they were willing to come, worked on such problems with considerable success in 1939 and 1940. Their success bred further demand for such services and the use of scientific teams spread over the Western Allies, the United States, Canada and France. These teams of scientists were usually assigned to the executive in charge of operations -- to the "line" -- and hence came to be known as Operational Research in the United Kingdom and by a variety of names in the United States: Operations Analysis, Operations Evaluation, Operations Research, Systems Analysis, Systems Evaluation, Systems Research, and Management Science. The name Operations Research was and is probably the most widely used.

At the end of the war very different things happened to OR in the United Kingdom and in the United States. In the United Kingdom expenditures on defense research were reduced; this led to the release of many OR workers from the military at a time when industrial managers were confronted with the need to reconstruct much of Britain's manufacturing facilities that were damaged by bombs. In addition, due to the election of the Labor Party, the nationalization of several major and basic industries was begun. Executives in nationalized basic industries, in particular, sought assistance from the OR men coming out of the military and received it. Coal, iron and steel, transport, utilities and many other types of industries began to create industrial OR.

In contrast to the situation in Great Britain at the end of the war, in the U.S. defense research was increased and military OR was expanded. Most of the war-experienced OR workers remained in the service of the military. Industrial executives did not call for help because they were returning to the familiar peace-time pattern, which did not involve either major reconstruction of plant or nationalization.

The eventual involvement of science in industrial problems of the executive type in the United States is due to the advent of the second Industrial Revolution. During World War II, scientific advances in the study of communication, control, and computation had surged ahead to produce the technological basis for automation: the replacement of man by machine as a source of control. In the late 40's the new revolution began when electronic computers became commercially available. The potentialities of these electronic "brains" as a new tool of management were broadcast far and wide and non-technically trained executives began to look for help in selection and utilization of computers. The emerging search for help was accelerated by the outbreak of the Korean conflict which placed increased demands on a large part of American industry. Therefore, in the early 1950's industry began to absorb some of the OR men who trickled out of the military; a few consulting firms, universities, institutes of technology, research institutes and governmental agencies began to absorb others. OR began to spread and expand.

In scarcely more than a decade OR broke out of its military shell and began to infiltrate business, industry and civil government. Since then, several hundred of the major companies in the United States, and corresponding numbers in Western European countries and Japan, have developed internal operations research groups and many more have used the services of outside groups. In the United States there are now at least 35 consulting groups in academic institutions, research institutes and consulting firms. Several nations including India, Egypt, France and Israel have used OR in national planning. Most agencies and departments of our federal government are using OR, in particular the Department of Health, Education and Welfare, primarily in the health area. Local governments are using OR in city and regional planning.

Graduate courses in operations research are given at more than 30 American universities and institutes of technology, some of which also award

advanced degrees for work in this area. Academic programs in operations research are also offered in many other countries, among them Italy, France, India, Israel, Holland, England, Belgium, Canada and each of the Scandinavian countries. There are six journals published in English, others in French, German, Italian Spanish and Japanese. There is also a veritable flood of books devoted to the subject. National operations research societies have been formed in about 20 countries and some of these are united in the International Federation of Operational Research Societies. There are now about 10,000 operations research workers throughout the world.

THE MEANING AND NATURE OF OR

Many definitions of OR and many arguments as to why it cannot be defined have been offered. In examining the definitions that have been offered one should keep in mind the fact that the old and well-established sciences, and even science itself, have never been defined in a way that is acceptable to most of their practitioners.

Definitions of OR should not be taken too seriously. In order to grasp its meaning we should rely more on understanding its essential characteristics, but a definition may be a useful guide to discussion of these characteristics. OR can be said to be

(1) research on problems involving the control of organized (man-machine) systems to provide solutions which best serve the purposes of the organization as a whole

(2) by interdisciplinary teams

(3) through the application of scientific method

The essential characteristics of OR identified in the definition are (a) its systems (or executive) orientation, (b) the use of interdisciplinary teams

and (c) the application of scientific method to problems of control. We now consider each of these in more detail.

The Systems (or Executive) Orientation of OR

This orientation is based on the observation that, in organized systems, the behavior of any part ultimately has some effect on every other part. Not all these effects are significant or even capable of detection. Therefore, the essence of this orientation lies in the systematic search for significant interactions in evaluating actions or policies of any part of the organization.

This way of approaching organizational problems is dramatically opposed to the one involved in "cutting a problem down to size." OR workers almost always enlarge the concept of a problem that is initially presented to them to include interactions not incorporated into its formulation by management. In order to deal with these enlarged -- and hence more complicated -- problems, new research methods have had to be developed involving the application of scientific method.

The Interdisciplinary Team

The division of the domain of knowledge into specific disciplines is a relatively recent phenomenon, largely a product of the 19th century. Until about the end of the 17th century it was possible for one man to learn and retain most, if not all, of the "scientific" knowledge that mankind had accumulated. Hence there was no need for specialization and all pursuit of knowledge was called philosophy. As the stock of knowledge began to exceed the storage capacity of the human brain, specialization began to take place. Natural philosophy came to be distinguished from traditional non-empirically oriented philosophy. Later it came to be known as natural science. Starting in the middle of the last century, natural science was divided into physics and

chemistry. A short while later biology began to be individuated and just before the end of the century, psychology as well. The social sciences came into their own early in this century. Each of these have been further divided and subdivided. Today we have more than a hundred scientific disciplines.

We have become so accustomed to classifying scientific knowledge in a way that corresponds to the departmental structure of universities that we act as though nature were structured in the same way. Nothing could be further from the truth. There are no such things as physical problems, biological problems, psychological problems, economic problems, and so on. There are only problems; the disciplines of science represent different ways of looking at them. Any problem may be looked at through the eyes of every discipline. But, of course, it is not always fruitful to do so.

If we want to explain an automobile's being struck by a locomotive at a grade crossing, for example, we can do so either in terms of the laws of motion, or the engineering failure of warning devices, or the state of health of the driver, or his mental state, or the social use of automobiles as an instrument of suicide and so on. Which way we look at the event depends on the purposes behind our looking at it. If, for example, we want to prevent the event from re-occuring, we would look at it in a way that will yield an effective solution in the shortest time or at the lowest cost.

For most familiar problems with which we have had long experience, our experience indicates a fruitful way of looking at the problem. For unfamiliar and complicated problems we tend to use that way of looking at problems which is most familiar to us. Therefore, it is not surprising that, given the problem of increasing productivity of a manufacturing facility, the personnel psychologist will try to select better workers or improve the training that they

are given. The mechanical engineer will try to improve the machines. The industrial engineer will try to improve the plant layout, simplify the operations performed by the workers or offer them more attractive incentives. The systems and procedures analyst will try to improve the flow of information into and through the plant and so on. All may produce improvements, but which is best? For complicated problems we seldom can know in advance. Hence it is desirable to consider and evaluate as wide a range of approaches to the problem as possible. This is the reason for interdisciplinary teams of scientists.

Since more than a hundred scientific disciplines, pure and applied, have been identified it is clearly not possible to incorporate each into every research project. But it is desirable to have on a team, representation from as many disciplines as possible and to have the team's work subjected to critical review from as wide as possible a variety of disciplines which are not represented on the team.

The Method of OR

In most discussions of the method of science, experimentation is cited as being essential. Unfortunately, however, experimentation is often not possible or practical where governmental, military or industrial organizations are involved. In industry, for example, a company cannot run the risk of financial failure in order to conduct a successful experiment. Experimentation can and should play an important role in OR but, more likely than not, the system cannot be subjected to it and some different approach must be taken in the majority of cases.

A suggestion can be found in the method of astronomers who are in much the same situation as the operations researcher (athough this may change

in the near future). The astronomer can observe the system he studies but not manipulate it. Therefore he constructs <u>representations</u> of the system and its operations, that is, <u>models</u> on which he conducts his research. The OR worker must usually do the same.

In OR, models take the form of equations which -- although they may be complicated from a mathematical point of view -- have a very simple underlying structure:

$$P = f(C_i, U_j)$$

where

P is a measure of the system's performance

C_i are the variables which can be controlled

U_j are variables (and constants) which are not controlled but affect P, and

f is the relationship between P and C_i and U_j

In addition, one or more equations or inequations are frequently required to express the fact that some or all of the controlled variables can only be manipulated within limits. These facts constitute the constraints on the solution. For example, the amount of machine time allocated to products cannot be less than zero or greater than the total time available; the sum of the amounts of money budgeted to different departments of a company cannot exceed the total amount available. The performance equation and the constraints together constitute the model of the system, and of the problem which we want to solve. Hence it is a <u>decision</u> as well as a <u>system</u> model.

Once the model is constructed it can be used to determine what values of the controlled variables will produce the best performance of the system for specified values of the uncontrolled variables; that is, we can <u>derive a solution</u> to the problem from the model. This may be done in two ways.

We can conduct experiments on the model. Such experiments are called simulations. In many cases, however, we can determine from the structure of the model what the solution is without simulation, that is, deductively, by analysis, rather than inductively.

The optimizing values of the solution improve the system's performance only if the model is a good representation of reality. Hence the model and the solution require testing and evaluation, respectively. Furthermore, if the decision under study is one that will be made more than once, it is very likely -- considering the nature of the systems studies in OR -- that the values of the uncontrolled variables or even the structure of the system will change with time. Hence, significant changes must be detected and the solution must be adjusted as required by them. That is, solutions that are rules for repetitive decisions or decisions that extend over periods of time must be controlled.

Finally, since the objective of OR is not merely to produce reports but to improve the performance of systems, the results of the research must be implemented if they are accepted by the decision makers. It is in this phase that the ultimate test and evaluation of the research is made and here that the operations researcher has the greatest opportunity for improving his own practices.

Summarizing, we have identified six stages of an OR project:

1. Formulating the Problem
2. Constructing the Model
3. Deriving a Solution
4. Testing the Model and Evaluating the Solution
5. Controlling the Solution
6. Implementing the Solution

OPERATIONS RESEARCH AND EDUCATION

Operations Research and the field of education have met many times in the past, but not very often over questions involving instructional media. As one might suspect, there have been a number of applications of OR to normal operating and housekeeping problems of educational institutions; for example, to the purchase and storage of supplies and equipment, to the operation of cafeterias, to the evaluation of parking policies and to the scheduling of students, faculty, classes, classrooms and examinations. Several studies have been done on libraries of institutions of higher learning. These have covered operating rules, determination of facility requirements and the question of centralization versus decentralization of facilities.

OR has also been used in developing long-range plans for institutions of higher learning. These have involved forecasting future enrollment by department and determining what combination of physical facilities, faculty size, teaching loads, class size, rank mix, salaries and tuition charges will best meet educational and financial objectives.

OR workers have been experimenting with a restricted class of instructional media. At the Operations Research office of Johns Hopkins University, and later at Case Institute of Technology, Dr. Ellis A. Johnson has attempted to develop the creative capabilities of precollege students by involving them in team research on important social problems. The reports turned out by these teams are striking evidence of his success, but even more striking is the record of subsequent contributions of these students to the professional literature of their chosen fields and the percentage of them going on to graduate work.

Only this last summer at Case we extended Johnson's idea by involving high school teachers of mathematics and science in research teams made up of faculty and graduate students working on sponsored research. The impact of this experience on their teaching cannot be assessed yet but, if their testimonials have any validity, it has had very significant value to them.

OR has been instrumental in the development and use of operational gaming as an instructional medium. In operational gaming some type of real system -- industrial, military or governmental -- is simulated in such a way that students can participate as decision makers do in the real situations. Military gaming, of course, is a very old way of training officers, but only recently has this medium been extended to training managers and administrators of non-military public and private enterprizes. It is even being used to train potential and professional diplomats.

At Case we are currently involved, in collaboration with IBM, in extending this idea to the education of research (rather than managerial) personnel. By working with computer-simulated systems, graduate students for the first time will have the opportunity to develop in class their ability to identify, diagnose and formulate problems, as well as their ability to solve them.

These contacts between OR and educational media are, of course, quite specific and have little relevance to the broad questions to which this conference is addressed. Therefore I should like to try to formulate what might be called the General Educational-Media Problem, but I would like to do so by analogy with another type of media problem with which OR has had considerably more experience-advertising media.

The typical advertising manager is confronted with the following set of interdependent questions; that is, questions whose answers are interrelated.

1. What is the total amount that should be spent on advertising per year (or some other planning period)?
2. How should this amount be allocated to different media (TV, radio, newspapers, magazines, billboards and others)?
3. For what kind of message (content) is each medium most effective?
4. How should the use of the various media be scheduled?

The translation of these questions into ones relevant to the educational manager is too obvious to labor over here. However, even though the same types of questions are relevant to both education and advertising, the problems involved in answering them are different in at least one important way.

In either case the four questions can be answered if we know what the cost and effectiveness is for each possible combination of media and message. In advertising, costs are easily obtained and measures of effectiveness -- that is, additional sales produced -- can be measured if advertising experiments can be run. Such experiments are usually quite costly and involve large risks to the company involved. Hence, OR has had few opportunities to conduct such experiments. Where it has, the results have been of considerable value.

In the educational context, it seems to me that the experiments required to answer these questions should not be costly nor should they involve significant risks to either the educational "supplier" or "consumer." But there is a rub. In advertising, the appropriate measure of media-message effectiveness is relatively clear, the amount of sales produced. What corresponding measure is to be used in evaluating instruction?

The first answer that comes to mind -- performance of students on examinations -- must be looked at sceptically. Advertising agencies have long tried to evaluate advertising the easy way -- by testing or examining potential consumers for their recall of the message delivered. However, there is now ample evidence that recall and sales are not significantly correlated. Other kinds of tests -- for example, verbal tests of product appreciation -- have yet to be shown to be any better. In advertising, the relationship between performance on a test and what is ultimately desired -- sales -- has yet to be established.

To develop effective tests of the effect of education, that which is ultimately desired (the objectives of educational efforts) must be made explicit and defined so as to be operationally meaningful and measurable. It is here, in my opinion, that OR can make a significant contribution to the advancement of educational-media research.

The development of appropriate measures of effectiveness has been a recurrent task of OR first in military, then in industrial and, more recently, in governmental and public contexts. At the moment, for example, we at Case are working on the development of such measures for medical and dental health programs, urban transportation systems, and national planning in underdeveloped countries. Ultimate measures of effectiveness will not be obtained in any of these situations but improved measures can and are being obtained.

I can suggest one possible approach to the problem of evaluating educational media which are intended to communicate to students. In recent years we have developed an understanding of the process of communication. Several years ago (Ackoff, 1958) I tried to formulate operational definitions and measures of the modes of communication and since then we have used these measures to

evaluate scientific articles and a specific effort at instruction (Martin, 1963). This work may be very briefly, and inadequately, summarized as follows:

Communication is the process by which, with the use of messages, one purposeful individual can affect the purposeful behavior of another. An individual can be said to be in a purposeful state if he has alternative courses of action available to him which have some, but unequal, efficiency for obtaining a desired outcome. The components of a purposeful state, therefore, are

1. the individual
2. the available courses of action,
3. the possible outcomes, and
4. the environment.

Three measures are sufficient to characterize a purposeful state:

1. for each course of action, the probability that the individual will select it -- probability of choice
2. for each combination of a possible course of action and a possible outcome, the probability that the course of action will produce that outcome -- efficiency of choice; and
3. for each outcome, its value or utility to the individual.

The value of his state to the individual involved is a function of these three measures and can be expressed in precise quantitative terms.

The <u>modes</u> of communication can be characterized as follows: a message that changes an individual's probabilities of choice <u>informs</u> (or misinforms)

him; a message that changes the efficiencies of courses of action instructs (or misinstructs) him; and a message that changes the values that an individual places on outcomes motivates (or demotivates) him. A single communication may, of course, do any combination of these simultaneously.

I have developed measures of the amounts of information, instruction and motivation that are communicated by a message, as well as measures of the separate and collective value of these to the receiver and the sender. Miles Martin and I recently have used these measures to evaluate a specific instructional effort (Martin, 1963).

A group of students was given a set of three- and four-digit numbers (selected at random) from which they were to extract the square root. They could use either a slide rule or a desk calculator. From their efforts it was possible to determine the probability that they would use the desk calculator and the efficiency with which they used it. They were then given a set of instructions on the use of the desk calculator for extracting square roots. After they had a chance to absorb these instructions they were given other sets of problems to solve. Probabilities of choice and efficiencies for these sets were determined. The differences in probability of choice and efficiencies between their work before receiving the instructions and their work after permitted us to measure the amount of information and instruction communicated to each student and, hence, the average of these measures over the group.

In this very simple situation it was relatively easy to measure changes in probability and efficiency of choice. It will not be so easy in most educational contexts. Where the information, instruction and motivation involved are, in some sense, more general, relevant choice situations will be more difficult to construct. For example, how should the communication of historical

information be evaluated? It is difficult to conceive of a situation in which one's course of action ought to be affected by knowledge of, say, the French Revolution. Yet, unless we can do so, we really have no rational justification for teaching this revolution. If the purpose of studying history is, as Santayana said, to avoid the errors of the past, it is either possible to construct meaningful situations in which these errors can be made or avoided, or the purpose of such study is fictitious. I believe that educators and operations researchers working in close collaboration can construct meaningful situations in which the amount of historical information that is available to a decision maker can be meaningfully measured. Furthermore, I believe such exercises would provide educators with an invaluable opportunity to systematize and state precisely the now-vague assumptions on which so many educational decisions are based.

I am aware of the fact that what I am suggesting has a very strong "instrumentalist" flavor and that education is, in some sense, at least partially an end-in-itself. That is, my emphasis has been on the extrinsic rather than the intrinsic value of education. But even the intrinsic value must have some operational meaning. Does it mean that educated persons will enjoy certain things more than the noneducated; for example, reading novels or history, listening to classical music, or observing great works of art? If so, this can certainly be observed and measured. Does it mean that educated persons are more adaptable to changing conditions or are better citizens, parents or friends? If so, these too can be tested. If the purpose of certain educational efforts is to sharpen the thinking process or discipline the mind or encourage creativity, these can be observed and measured as Ellis Johnson has done. If not, what meaning can such educational efforts have?

The particular measures of communication that I have developed present many practical problems and hence require considerable modification before they are widely usable. The concepts of the modes of communication, however, are -- in my opinion -- immediately applicable to qualitative evaluation of specific educational media in specific contexts. When more useful measures than mine are developed, experiments can be designed and conducted which will yield the measures that are required to answer the four questions that constitute the general educational-media problem that I formulated earlier.

CONCLUSION

I have outlined only in broadest strokes one possible approach to the use of OR in evaluating educational media and in designing educational programs. I have not suggested that OR can provide a panacea to educators' problems. OR's success in other domains, however, suggests that educators would be remiss not to explore thoroughly the possible usefulness of OR in improving their design of educational programs.

It should be remembered, however, that the quality of OR is at least as variable as the quality of education. The quality of the results obtained by applying OR to educational problems will be no greater than the quality of the operations researchers who are put to work on the problems. Even the best of men will require patient support and aid over a substantial period of time if progress is to be made.

REFERENCES

Ackoff, R. L., "Towards a Behavioral Theory of Communication," Management Science, 4 (April 1958), pp. 218-234.

Martin, M. W., Jr., "The Measurement of Value of Scientific Information," in Operations Research in Research and Development, ed. by B. V. Dean, John Wiley and Sons, New York, 1963, pp., 97-123.